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Studying the potential of multi-carrier energy distribution grids: A holistic approach

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ABSTRACT

Integrated operation of distribution grids for multiple energy carriers promises hitherto unused synergies in terms of efficient generation, storage, and consumption. A major obstacle to the investment in such systems is their increased complexity, as conventional tools and methods were not designed to capture all relevant technical and economic aspects of hybrid grids. To address this obstacle, this work proposes a methodology to systematically assess multi-carrier energy grids under a holistic scope. By adopting a simulation-based approach that relies on detailed technical and economic models, an efficient and precise evaluation of both short-term (operational) and long-term (strategic) aspects is supported. The methodology enables the assessment of system configurations, control strategies, business models, and regulatory conditions in one coherent approach. As a proof-of-concept, the new methodology is applied to a real-world use case of a hybrid thermal-electrical distribution grid in a central European city. The results are comprehensively discussed to showcase how the various aspects of hybrid energy systems are addressed. The outcomes also demonstrate how this methodology aids the involved stakeholders in understanding the associated risks and potentials, paving the way for early adopters to realize multi-carrier energy distribution grids.

1. Introduction

Energy system integration is targeting the convergence of infrastructure for different energy carriers, which has recently become a major focus of research and development [1]. An important aspect of this convergence is to jointly operate the distribution grids across multiple energy carriers. The idea of coupling existing network infrastructures to obtain so-called *hybrid networks* promises to utilize hitherto unused synergies in generation, storage and consumption [2,3]. The increased reliability and flexibility of such hybrid networks is also expected to lower the barrier towards integrating a larger share of volatile renewable energy sources.

Within the context of this work, a potential implementation plan for an integrated multi-carrier energy distribution system – including both technical aspects (system configuration, operational strategy) and strategic aspects (business model, regulatory frame) – is referred to as a *hybridization scheme*. The technology required for most hybridization schemes is already mature and available at the component level. However, this does not apply to the system level, where the mutual influence of the networks and the resulting implications are not yet understood well enough. Similarly, plans for coupling multiple energy carriers in hybridization schemes raise new questions regarding economic and regulatory feasibility, which are beyond today's best practices for the individual domains. The challenge is to provide a holistic approach for designing and assessing hybridization schemes, addressing the full range of related questions.

This challenge has been addressed by the OrPHEuS project. To overcome the current lack of off-the-shelf tools and methods for investigating hybridization schemes, a new holistic approach for studying the potential of hybrid networks has been devised and implemented. The project specifically focuses on the assessment of

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innovative *control strategies* and *business cases* for hybrid networks, taking into account their impact on day-to-day operations, economic long-term objectives, as well as regulatory boundary conditions. The project's targets have been achieved employing a two-stage model-based investigation process, relying on an interplay of high-resolution technical simulations (using co-simulation to include multiple energy domains) and long-term economic model calculations. The result of these integrated assessments are a collection of technological (operational) and economic (strategic) recommendations for the relevant stakeholders. To the best of our knowledge, the OrPHEuS project is the first to develop an investigation methodology for hybridization schemes with such a broad scope. A comparison with related work is provided in Section 3.

This work extends a preliminary description of the OrPHEuS methodology given in Ref. [4] by a more systematic discussion of the full range of conceptual aspects. To this end, Section 2 categorizes the range of grid coupling points and stakeholders to consider and establishes the set of requirements for a holistic evaluation methodology. A discussion of related work is given in Section 3. Section 4 then presents the chosen methodology and discusses the approach in light of the requirements. The actual implementation in terms of tools and methods used by the OrPHEuS project is presented in Section 5. An application to a real-world use case is presented in Section 6, demonstrating the benefits of the methodology and showing the applicability of the developed tools. Section 7 summarizes and concludes this work.

2. Requirements for the assessment of hybrid networks

2.1. Determining factors for the assessment of hybrid networks

Hybrid networks are realized through the physical interconnection and joint operation of distribution grids of different energy carriers. From a technical perspective, this is accomplished with the help of *coupling points*, i.e., devices which directly or indirectly enable the exchange of energy across carrier domains. For the purpose of this work, coupling points are classified into the following categories:

- *Co-generation units* are generators that can flexibly supply energy for multiple grids, e.g., combined heat and power (CHP) plants.
- *Conversion devices* consume energy from one grid and generate energy for another, e.g., heat pumps, e-boilers, or power-to-gas systems.
- Also *consumers* can play the role of coupling points if they are able to cover their energy demand from more than one network, e.g., domestic hot water systems that use either a gas boiler or an e-boiler.

This diverse range of technologies for coupling points is matched by an equally diverse range of stakeholders having different and sometimes competing interests:

- For *energy providers*, hybrid networks can offer benefits by enabling businesses beyond the traditional borders of single-carrier networks, e.g. by the ability to sell energy across multiple grids. On the other hand, such enhanced markets may also lead to new forms of competition.
- For *distribution system operators* (DSO) the benefit of hybrid networks is clearly the potential increase in flexibility due to new synergies in production, storage and demand, e.g., local consumption of photovoltaic energy by power-to-heat coupling points. However, the DSO's preferred operational strategy may be incompatible with the interests of other stakeholders and the existing regulatory framework.
- For *consumers* and (small-scale) *prosumers* the potential benefits of hybrid networks are related to security of supply, e.g., environment-friendly heat supply even during exceptionally cold periods, and increased market participation, e.g., virtual power plants for local consumption of electricity from photovoltaic (PV) systems.

For any given hybridization use case, the interests of the involved stakeholders can be translated to both operational *and* strategic goals. Hence, in order to provide meaningful recommendations, a *holistic approach* is required that considers both technical and economic aspects. In the subsequent section, the detailed requirements for the technical and economic assessment are established.

2.2. Requirements for technical and economic assessments

Even though the market offers a wide range of technically mature grid coupling points, their integration is often not well understood from a system level perspective. Especially for DSOs this is an obvious obstacle for implementing hybrid networks, as they have to guarantee stable network conditions and security of supply. For this reason, a meaningful technical assessment must meet the requirements listed in the upper part of Table 1.

In addition to the technical aspects, hybridization schemes have to be validated regarding their economic feasibility in order to verify the long-term monetary benefits for all stakeholders. This kind of assessment needs to provide an analysis of currently existing structural barriers and help with the design of business

Table 1
Requirements for the assessment of hybrid networks.

Requirements for technical assessments	
R1	For the overall evaluation of the hybridization scheme, the technical assessment has to capture the dynamic interactions between the networks on the system level.
R2	The technical assessment has to be done in a way that allows experts from all involved technical domains to actively participate in the process.
R3	For the feasibility evaluation of a proposed operational strategy, the technical assessment has to provide a detailed evaluation down to the component level of the individual networks.
R4	For the design and validation of new control schemes, the technical assessment has to include all types of controllers from the system level down to the process level. It also has to accurately reproduce their impact on and the response from the networks.
Requirements for economic assessments	
R5	The economic assessment needs to include a description of the technology portfolio considered in the business model. This also requires a (simplified) model of how the corresponding devices are affected by the operational strategy.
R6	The economic assessment requires clearly defined business models that specify which market participants are involved and what their roles and responsibilities in these new business models are.
R7	Based on an operational strategy and a business model, the economic assessment has to perform an economic trade-off analysis. This analysis has to consider regulatory aspects, conditions for new business models, and make sure that mutual benefits are guaranteed.